MILLIMETER-WAVE IMAGING RADIOMETER (MIR) DATA PROCESSING AND DEVELOPMENT OF WATER VAPOR RETRIEVAL ALGORITHMS

Prepared for

National Aeronautics and Space Administration

Goddard Space Flight Center

Greenbelt, Maryland

by

Futuretech Corporation

Semi-Annual Report

under

Contract NAS 5-32705

April 1995

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ABSTRACT

This document describes the progress of the task of the Millimeter-wave Imaging Radiometer (MIR) Data Processing and Development of Water Vapor Retrieval Algorithms, for the first six-month performance period. Significant progress and accomplishment have been achieved. Raw data collected from airborne MIR observation during different field experiments and calibration campaigns have been processed and stored in a workstation computer.

A start-up version of MIR water vapor retrieval algorithm has been developed for use in the atmospheric humidity profiling. A special retrieval system is also established for the ingestion of microwave data from the spaceborne instrument of Special Sensor Microwave Water Vapor Sounder (SSM/T-2). It is capable of a three-dimensional (3-D) mapping of moisture distribution along the satellite suborbital swath.

Preliminary analyses and validation using available rawinsonde and LIDAR are performed. Collocated comparison of humidity retrievals between MIR and overpassed SSM/T-2 are made for near-concurrent observations. Results are discussed and follow-up technical endeavors are recommended.

1. INTRODUCTION

The development of remote sensing techniques using microwave sensors to detect atmospheric water content and surface properties has been one of the major research thrusts in Microwave Sensors Branch, Laboratory for Hydrospheric Processes. Millimeter-wave Imaging Radiometer is a recently built airborne sensor with frequencies ranging from 89 GHz to 220 GHz. Flown in a NASA ER-2 high altitude aircraft, MIR has taken measurements in different missions since May 1992. Major field observations include the Tropical Ocean-Global Atmosphere (TOGA)/Coupled Ocean-Atmosphere Response Experiment (COARE) of January-February 1993 in South Pacific, and the Convection and Moisture Experiment (CAMEX) of September-October 1993 in East Coast of the United States. Data is also collected from a calibration campaign during July-August 1992 over the East Coast and during December 1994 in the West Coast. There will be more scheduled flight missions and further MIR data will be collected for studies.

The task objectives are the establishment of MIR data processing systems on the platform of SGI workstations, including the image/graphics display facilities, the development of a near-real time retrieval algorithm, and the performance of water vapor retrievals and their validations.

In Chapter 2, data processing systems and relevant display packages are described. Chapter 3 gives a detailed description of the current version of the retrieval algorithm. Finally, Chapter 4 will summarize the performance of the water vapor retrieval and

their validation. Recommended follow-up efforts toward the technical objective of the task are given at the end.

2. DATA PROCESSING AND ARCHIVING, IMAGE DISPLAY

(a) MIR Data Processing

For each mission, the six-channel (89, 150, 183±1, 183±3, 183±7, and 220 GHz) scanning MIR aboard of NASA ER2 aircraft collects raw radiometric data that in turn are recorded in a 8 mm Exabyte tape. Data processing is performed on a SGI workstation platform. Procedures include the transfer of data from tape to hard disk and the execution of source programs in calibration, averaging and navigation positioning. Final products are in the form of calibrated brightness temperature for each channel and for each of 57 beam positions. Two subdirectories are created to store all processed MIR data.

As of this date, we have compiled calibrated MIR data from missions of 5 different measurement periods. They are:

(i) West Coast (2 flights) during May 1992

(ii) East Coast (6 flights) during July and August 1992

(iii) TOGA/COARE (11 flights) during January and February 1993

(iv) CAMEX (5 flights) during September and October 1993

(v) West Coast (2 flights) during December 1994

Further flight missions and more data collection will be scheduled in the future.

(b) SSM/T-2 Data

The spaceborne instrument SSM/T-2 on board of satellite of the Defense Meteorological Satellite Project (DMSP), is operating in

five microwave channels (92, 150, 183±1, 183±3 and 183±7 GHz). It provides global coverage in the moisture detection.

Data originally obtained from the Fleet Numerical Meteorology and Oceanography Center has been assembled in a SUN workstation by the Microwave Remote Sensing group at Texas A&M University. This data, packaged on CD-ROM, shows the calibrated brightness temperatures in 28 beam positions. They are transferred to SGI workstation at Microwave Sensor Branch, NASA/GSFC. A program is created to read the data and convert into SGI byte structure before feeding into the retrieval program.

Currently, a limited number of orbital data for September 1992, January and February 1993 has been processed for use in water vapor retrieval.

(c) Image and Graphic Display

Several useful graphics software packages have been purchased or imported from sources in the public domain.

(i) Interactive Data Language (IDL)

Purchased from a vendor, IDL is useful in displaying scientific data images. It has been used to display SSM/T-2 images and the retrieved humidity cross section.

(ii) DIUTIL

Installed by Futuretech Corporation (FTC) personnel, it facilitates global mapping of geophysical parameters in a one-by-one grid system.

(iii) Transportable Application Executive (TAE)

Imported from Mesoscale Dynamics and Precipitation

Branch, Laboratory for Atmospheres, it is useful for taking quick looks at MIR processed brightness temperature.

(iv) VIS5D

Installed by FTC personnel, it is useful in two-dimensional and three-dimensional visualization of geophysical fields.

(v) ACE/GR

Installed by FTC personnel, it is useful graphic software for scientific two dimensional (x,y) plots.

(vi) XV

A built-in software provided from a vendor, it is a user-friendly package using a widget window application. Input data can be accepted in Graphics Interactive Format (GIF) and in Hierarchial Data Format (HDF).

3. DEVELOPMENT OF WATER VAPOR RETRIEVAL ALGORITHM

(a) Retrieval Methodology

The retrieval algorithm is based upon a physical relaxation method for the solution to the inversion problems of the radiative transfer equation (RTE) in the microwave spectrum.

For a given set of observed upwelling brightness temperature, RTE is solved numerically using iterative estimation procedure of Kalman-Bucy filtering, for the desired humidity profile. The solution is considered satisfactory when the rms error between the computed and the observed brightness temperature falls within tolerable ranges. Some aspects of the numerical procedure are relevant:

(i) Construction of quadrature atmospheric models in z-mesh system.

Currently, one dimensional atmospheric models for the radiative transfer calculation is done through a 41 grid points system extending from the surface (z=0) to top at z=20 km, with evenly spaced $\Delta z=0.5$ km. Temperature, pressure, and humidity are evaluated at each grid point. Optical depth is computed using layer mean quantities. A total of 40 layers in this model is decided to keep the truncation error pertaining to finite differencing small and yet keep the computation time affordable.

(ii) Input of temperature and pressure fields.

With the z-mesh system described in (i), the temperature and pressure profiles are derived from the European Center for Medium Range Weather Forecast (ECMWF) model output in 12-hour intervals.

Database archived in UNITREE mass storage system is provided by Data Assimilation Office (DAO), Laboratory for Atmospheres. Data extracted from UNITREE are further interpolated bilinearly in horizontal space and linearly (temperature) or logorithmicly (pressure and moisture) in the vertical.

(iii) Initialization and convergence criterion.

Initialization of the humidity profile has some impact on the final retrieved profile due to the non-uniqueness property pertained to the numerical solution of the integral equation and the stringency of the convergence criterion. For case of a clear column retrieval, this effect can be controlled through the use of more stringent convergence criterion. For general meteorological conditions, this dependence on the initial profile is subject to further investigation, although the gross picture of the retrieval result is not significantly affected.

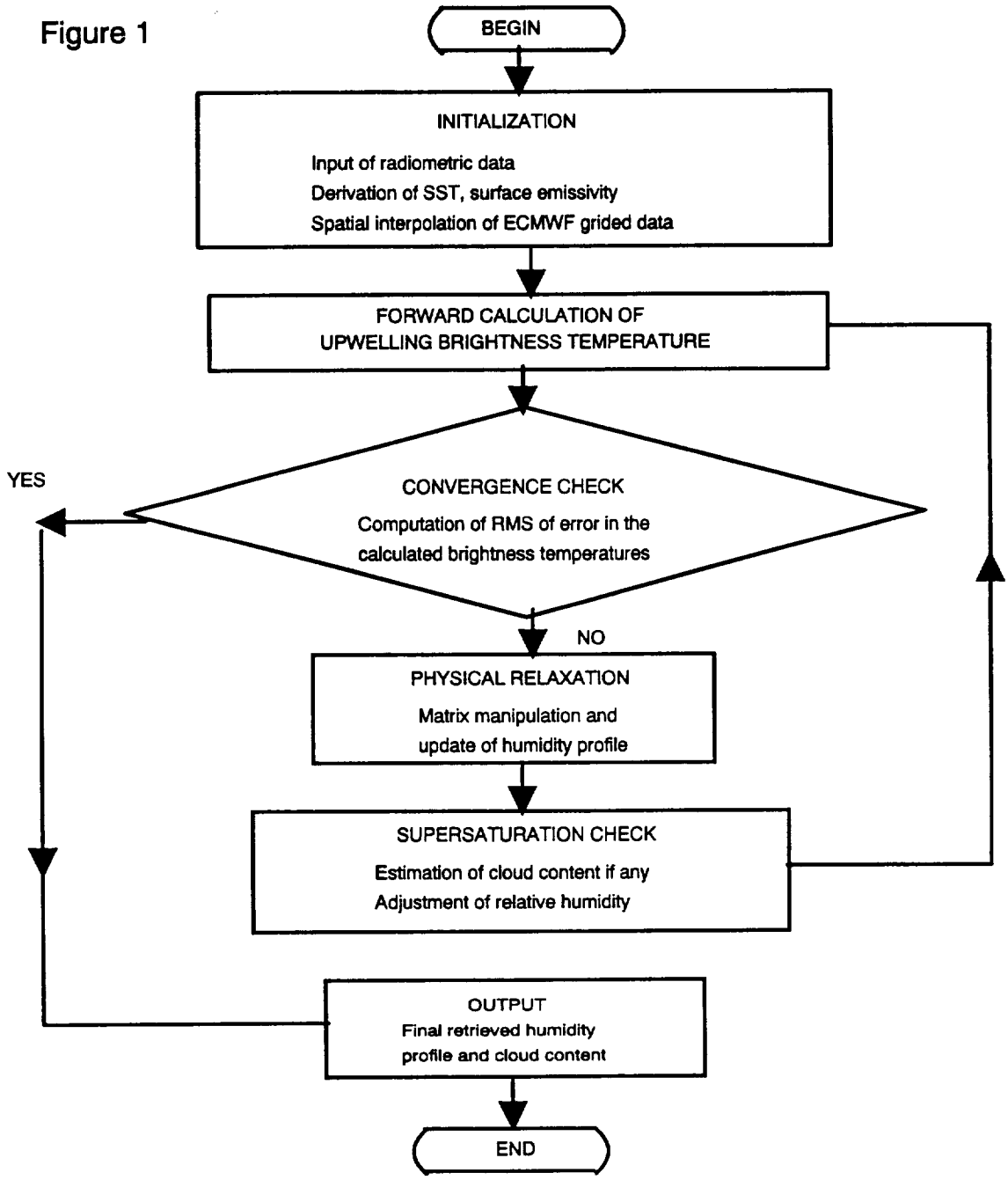
For the simplicity in the mathematical inferencing theory, the number of reference levels for humidity retrieval is currently set equal to the number of channels of the input radiometric data.

Extension of the current algorithm to retrieve more information such as surface emissivity or humidity at a specific level is subject to subsequent development.

(iv) Execution sequence and saved products.

Figure 1 shows the schematic flow chart of the execution of the water vapor retrieval algorithm.

Figure 1


BEGIN
INITIALIZATION
Input of radiometric data
Derivation of SST, surface emissivity
Spatial interpolation of ECMWF grided data
FORWARD CALCULATION OF
UPWELLING BRIGHTNESS TEMPERATURE
CONVERGENCE CHECK
Computation of RMS of error in the
calculated brightness temperatures
YES
NO
PHYSICAL RELAXATION
Matrix manipulation and
update of humidity profile
SUPERSATURATION CHECK
Estimation of cloud content if any
Adjustment of relative humidity
OUTPUT
Final retrieved humidity
profile and cloud content
END

The final products are saved in the respective execution subdirectory. These include the retrieved water vapor profile in terms of relative humidity and mixing ratio. Along with the necessary navigation data, precipitable water is also included.

(b) MIR Algorithm and SSM/T-2 Algorithm

Since MIR and SSM/T-2 operate at similar microwave frequencies (MIR has one extra window channel at 220 GHz), the logical design of the retrieval algorithm for these two instruments remains the same as described in Figure 1. Pertaining to the difference in the number of observing channels, MIR algorithm retrieves humidity at six distinct levels while SSM/T-2 retrieves at five levels only.

The major difference is the determination of the observed brightness temperature in the forward calculation. Pertained to the difference in the instrumentation characteristics, for the off-nadir pixels, MIR measures the brightness temperature that is the combination of the vertical and horizontal polarizations according to:

$$T_b(\theta) = T_{bh}(\theta)\sin^2\theta + T_{bv}(\theta)\cos^2\theta \quad (1)$$

while the SSM/T-2 measures:

$$T_b(\theta) = T_{bh}(\theta)\cos^2\theta + T_{bv}(\theta)\sin^2\theta \quad (2)$$

Where θ is the off-nadir angle. T_{bh} and T_{bv} are the calculated brightness temperature components of the horizontal and the vertical polarization respectively.

4. RETRIEVAL INTERCOMPARISON AND VALIDATION

(a) Collocated Retrieval

Current version of water vapor retrieval algorithm as described in the preceding chapter is used to perform a 3-D humidity mapping along the MIR flight path and along the SSM/T-2 suborbital swath as well. Near-concurrent and collocated observations of these two sensors are used for retrievals and comparisons are made for July 29, 30 and August 6, 1992 in the U.S. East Coast, and for February 10, 1993 in TOGA/COARE South Pacific. A 2-D cross section (in the x-z plane) of the retrieved mixing ratios along the collocated flight path of each sensor is plotted and compared with each other. Results show general agreement for the two sensors. The latitudinal variation in water vapor content is depicted quite well in both retrievals. Profile retrievals using SSM/T-2 data are also compared to TOVS derived layer precipitable water at collocated spots. Scattered plots show a general underestimation in the TOVS derivation as compared to SSM/T-2 retrieved profiles. These results are to be reported in the International Geoscience and Remote Sensing Symposium (IGARSS '95).

b) Validation Studies

Preliminary validation studies are conducted using the following available in situ concurrent measurements:

(i) radiosondes

(ii) ground based Raman Lidar

(iii) dropsondes

The first two measurements were made at the NASA/GSFC Wallops Flight Facility during July 29-August 6, 1992. Dropsonde measurements were performed during TOGA/COARE flight missions in the South Pacific. Preliminary results show a good agreement between the MIR retrieved water vapor and the measured result from other instrument. Specifically, the agreement is good at levels below 1.5 km and degrade with increasing altitudes. As results of this related study, two papers have been submitted for publication.

The first is entitled "Simultaneous Measurement of Atmospheric Water Vapor with MIR, Raman Lidar and Rawinsonde" is accepted by Journal of Applied Meteorology. The second one entitled "MIR Measurements of Water Vapor Profiles" is submitted to Geoscience Remote Sensing, IEEE Transactions.

5. RECOMMENDATION AND PLANNED WORK FOR THE NEXT PERFORMANCE PERIOD

Significant progress has been made in the task of MIR data processing and development of water vapor retrieval algorithm. This upgraded version of retrieval algorithm is capable of a three dimensional mapping of moisture distribution by using imaging data from airborne MIR and from spaceborne SSM/T-2 as well. Since there will be more flight missions and more data collections scheduled, radiometric data processing will be continued. These missions include observation over regions at higher latitudes where surfaces may be covered with ice and snow. Water vapor retrieval over such surfaces will be developed. The following are the recommended studies in the continued development of water vapor retrieval algorithms:

(i) Inclusion of the retrieval of surface emissivity in the current algorithm.

(ii) Extension of the retrieval algorithm to cover humidity retrieval over surfaces with ice and snow.

(iii) The conversion of the retrieval system from using z-coordinates to the use of pressure coordinates.

(iv) Exportation of the retrieval system to the CRAY/YMP supercomputer platform and to optimize the retrieval algorithm for improved throughput of the system.

(v) Performance of global water vapor retrieval using satellite data of SSM/T-2 and the comparison of the result to the layer precipitable water derived from

the TIROS-N Operation Vertical Sounder (TOVS) on board NOAA's polar orbiters.

(vi) Development of an improved cloud algorithm, so that microwave attenuation due to the presence of clouds is better represented.

(vii) Improvement of the algorithm to include an empirical attenuation function for rain, to increase the retrievability of the water vapor retrieval system.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1995	Semi-Annual (OCT 01,94-MAR 31,95)

4. TITLE AND SUBTITLE
Millimeter-Wave Imaging Radiometer Data Processing and Development of Water Vapor Retrieval Algorithms

5. FUNDING NUMBERS
NAS5-32705

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)
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8. PEFORMING ORGANIZATION REPORT NUMBER
95FTC001

9. SPONSORING / MONITORING ADGENCY NAME(S) AND ADDRESS (ES)
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

10. SPONSORING / MONITORING ADGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATMENT
Unclassified - Unlimited
Subject Category
This publication is available from the NASA Center for AeroSpace Information, 800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934, (301)621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This document describes the current status of Millimeter-wave Imaging Radiometer(MIR) data processing and the technical development of the first version of a water vapor retrieval algorithm. The algorithm is being used by NASA/GSFC Microwave Sensors Branch, Laboratory for Hydrospheric Processes. It is capable of a three dimensional mapping of moisture fields using microwave data from airborne sensor of MIR and spaceborne instrument of Special Sensor Microwave/T-2(SSM/T-2).

14. SUBJECT TERMS
MIR, Water Vapor Retrieval, SSM/T-2, Physical Relaxation

15. NUMBER OF PAGES
14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL